Shane van Bueren

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Logbook

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Reminders for me

Logbook requirements:

- *List any work accomplished and note down lessons learnt.*
- *Explain any design choices briefly + summarise concepts (more in-depth explanation of your design decisions should go in your design concepts and overview document)*
- *Include evidence and references (screenshots, photos, links etc.)*
- Note: readability should be a priority.

Project Deliverables

1. *A document investigating the feasibility of a sun-tracking solar panel.*
2. *At least 3 concept designs including strengths and weaknesses of each.*
3. *CAD model of sun-tracking **solar panel mount**.*
4. *FEAs showing that JAXA specifications are met.*
5. *3D printed model demonstrating proof of concept.*

Info from Sam:

- *Only need basic understanding of how solar panels work, not in-depth electronics*
- *Worry about the axis mechanism design first before full integration with CubeSat*

Week 1: 26/03 – 01/04

Week 1 Goals

- Attend first onboarding
- Read through Onboarding Handbook and do quiz
- Read through GitHub and familiarise with projects
- General CubeSat learning and research
- Select project by end of week

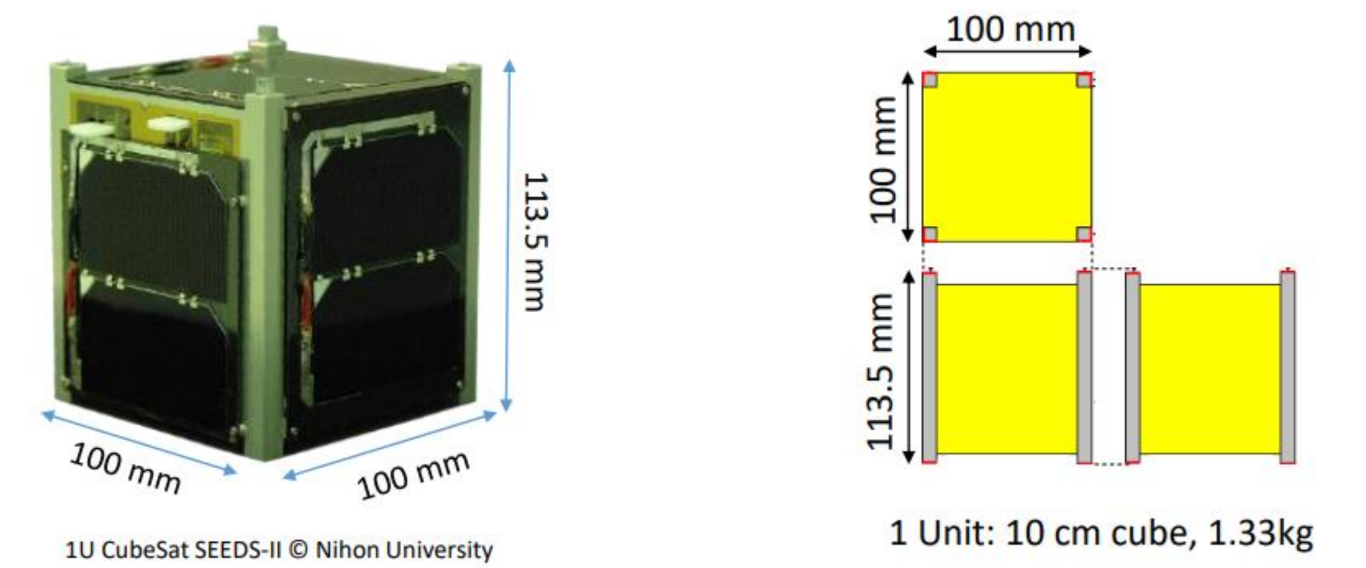
26/03
First onboarding session and familiarisation

- Familiarisation with GitHub and the range of projects on offer -> interested in doing mechanical
- Important to consider JAXA specifications for mechanical design

27/03
Familiarisation with CubeSat basics

- Reading of basic JAXA specs
    - Satellite must be 113.5+/-0.1mm tall in Z axis (deployment direction) and 100+/-0.1mm wide in X and Y axes
    - Satellite must have four rails on each corner along Z to slide along ejection case
    - Mass not more than 1.33kg

KiboCUBE academy



From: https://www.unoosa.org/documents/pdf/psa/access2space4all/KiboCUBE/AcademySeason2/On-demand_Pre-recorded_Lectures/KiboCUBE_Academy_2022_OPL18.pdf

29/03

Further research

- Further JAXA reading
  - Mass must not be less than 0.13kg and not more than 1.33kg
  - Centre of gravity must be located within a sphere of 20mm from geometric centre
- Reading of CubeSat 101 by NASA
  - Interesting -> 1) do not design to envelope limits, measurements should fall within tolerances. 2) double up on burn wire
  - Mechanical development -> to catch design issues early on, do thermal and vibration tests on subsystems prior to integration

01/04
Solar panel research and Inventor learning

Reading Articles from the GitHub:

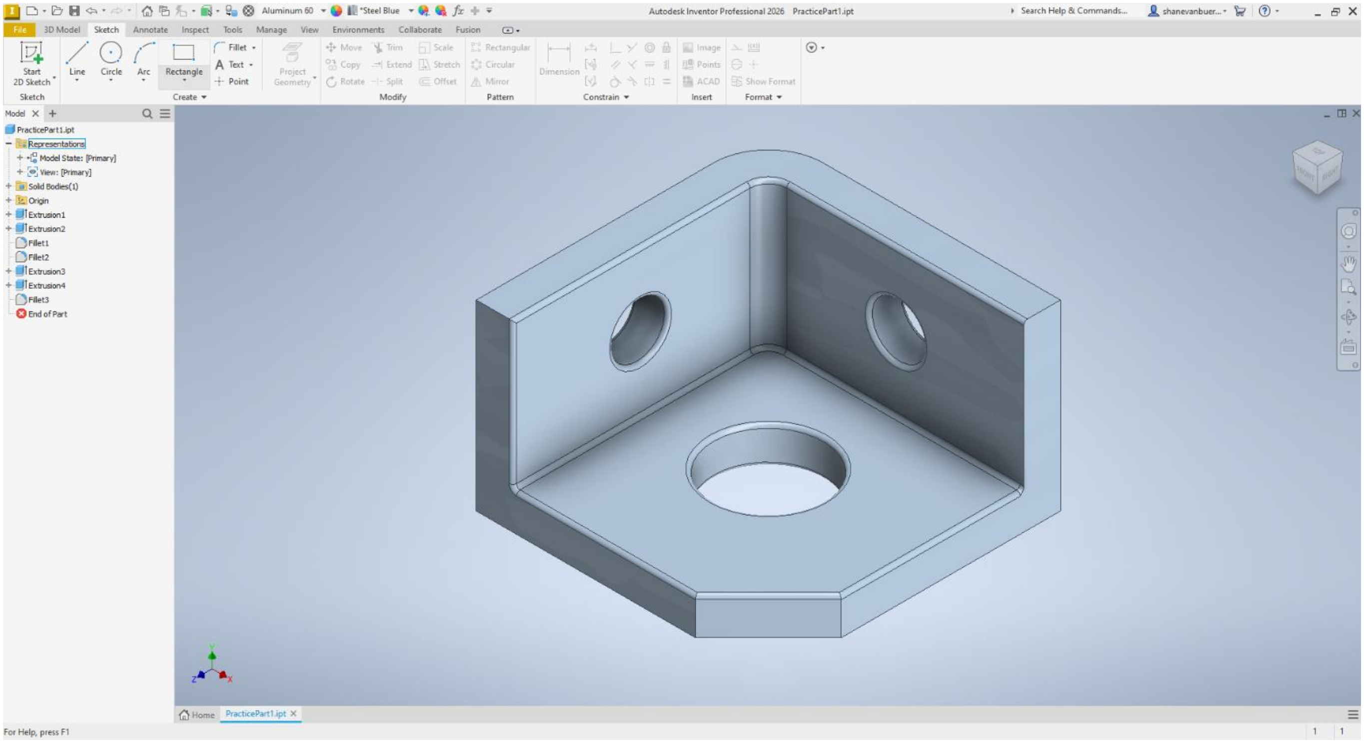
- University of Dayton Study - https://ecommons.udayton.edu/cgi/viewcontent.cgi?article=1172&context=uhp_theses
  - Highlights importance of sun tracking solar panels -> better energy generation due to always facing sun
  - Also lays out several different designs, including static, single and multi-axis arrays
  - Interested in 2 axes of rotation, such as with the ISS
  - Included info on the possibility of using Nitinol wire to actuate array orientation. A benefit of the wire is that it requires no power from the cubesat as it changes shape due to the sun's heat. It may be possible to use this material in this project.
  - A potential design from the team was to have a secondary array which, when receiving sunlight, would pass a current through Nitinol wire which would then orient the primary solar array.
- Mechanism designs for solar tracking https://nottingham-repository.worktribe.com/OutputFile/6845372
- Dwarf Planet Project study https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=3260&context=smallsat
  - Solar cells degrade over time -> may be good to design array with high energy output at beginning of mission

https://acceleron.org.in/index.php/aaj/article/view/212

- Great article on types of solar cells used in CubeSats and pros/cons (for later reference)

Started learning Inventor:

- I watched a YouTube video and learnt how to make a simple bracket
- Here it is:



Week 2: 02/04 - 8/04

Goals

- Brainstorm a timeline of project deliverables for each week
- Further research into 2 axis mechanisms

02/04

Timeline:

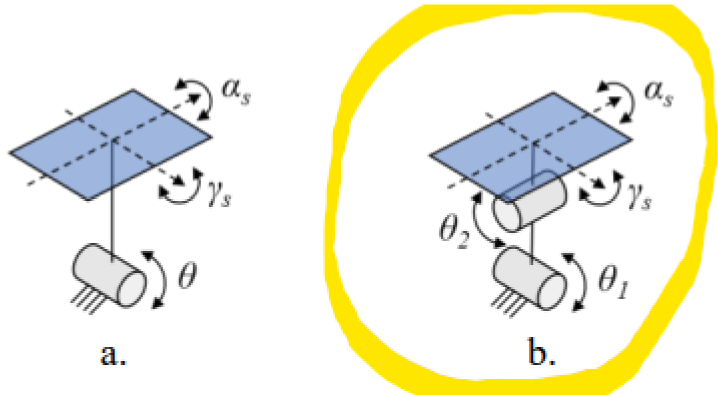
Wk 2: Research 2 axis mounts.
Wk 3: Pick 3 possible designs and research strengths/weaknesses.
Wk 4: Pick best and model design in Inventor.
Wk 5: Conduct FEAs showing that JAXA specifications are met.
Wk 6: Send CAD model to Sam/team for 3D printing. Write up draft Design Concept document.
Wk 7: Review 3D print and resend for another print if necessary. Further writing of Design Concept doc.
Wk 8: Final pass of Logbook and Design Concept documents + submission + victory

04/04

2 axis mechanisms

Mechanism designs for solar tracking
https://nottingham-repository.worktribe.com/OutputFile/6845372

- While parallel mechanisms are an area of interest for Earth applications due to their increased resistance to gravity and weather hazards, plus more accurate motion, I expect a serial mechanism to be more than enough for a zero G environment
- Looking at something like this two-axis tracker with an open-loop RR chain



- Open-loop meaning -> no feedback mechanism
- RR -> two revolute joints which allow rotation in a single axis each

Design and Implementation of a Dual-Axis Solar Tracking System:

https://www.researchgate.net/publication/373562701_Design_and_Implementation_of_a_Dual-Axis_Solar_Tracking_System

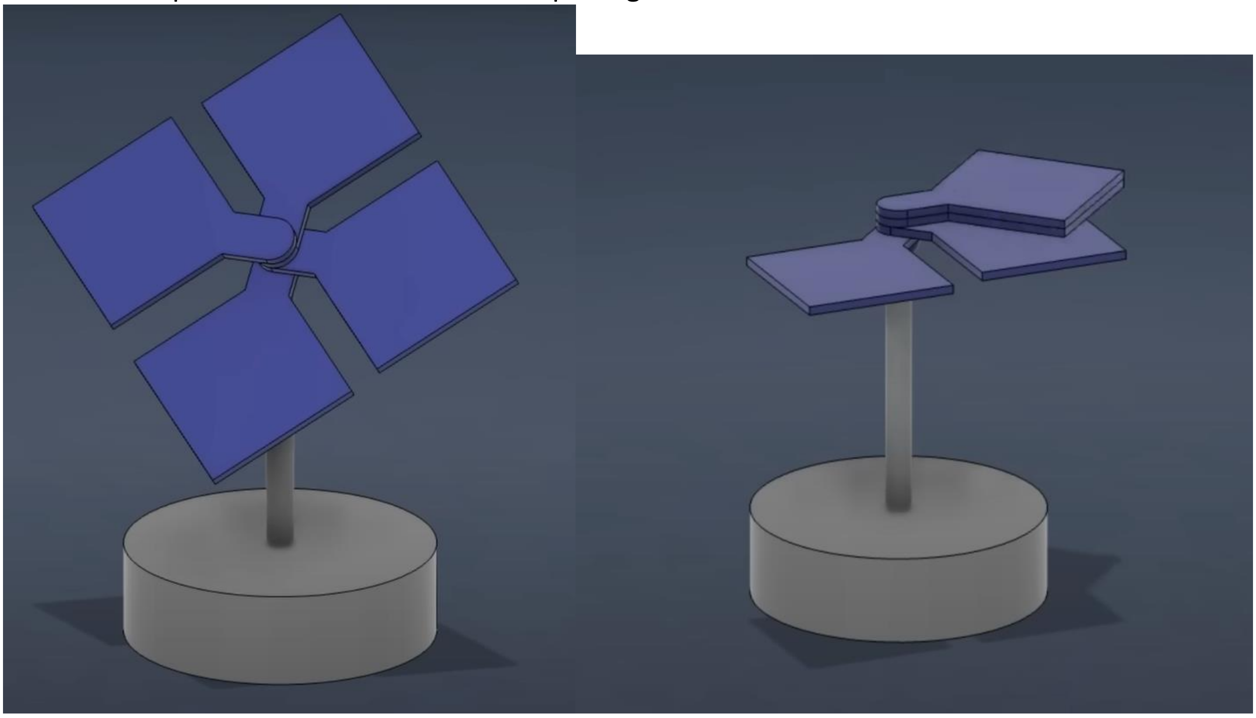
- The article describes the experimental results of a 2-axis solar panel system on Earth. When compared to a solar panel at a fixed 30-degree angle, the 2-axis tracking system collected 24.6% more energy.
- Reading this article made me realise that it is important to consider the energy expenditure used to control the solar panel rotation system. If it costs more energy to move the solar panels than it gains from the better position, the system it not worth it.
- For a system on earth, the article suggests that the solar tracking device of interest sees a far greater energy gain from optimal panel positioning compared to the energy spent on driving the system.
- Therefore, I expect that if I stick with simple stepper motors, it is unlikely that I will see the system using more energy than it produces, especially in a zero g environment where I don’t have to worry about gravity.
- The authors only need to activate their stepper motors for 30s every half an hour. Don't need to be constantly on.

08/04

Further investigation

https://www.youtube.com/watch?v=aHpVVMpBAfo&ab_channel=AxelMadeIt

- Cool video where a guy made a small sun tracking solar panel system
- Solar panels unravel like a flower opening:



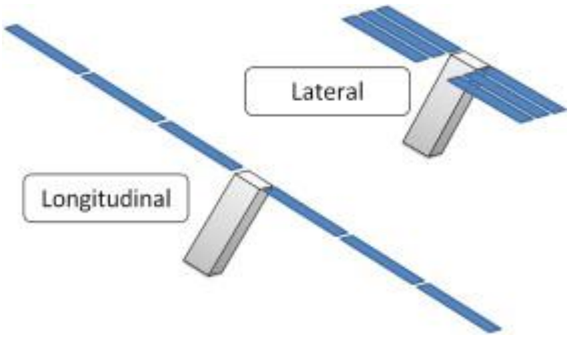
(Screenshots from AxelMadeIt on YouTube)

- This design shows potential in further increasing the amount of solar energy able to be captured by the array whilst being able to be deployed from a space about the same size as a single solar panel
- The 2-axis rotation of this design was achieved through rotation of the base for horizontal alignment and a single revolute joint for vertical alignment
- The design may be unnecessarily complex but is useful in consideration of what components can work together to achieve 2 axis tracking. Most notably, how the system controlling vertical alignment is attached onto the rotating base.

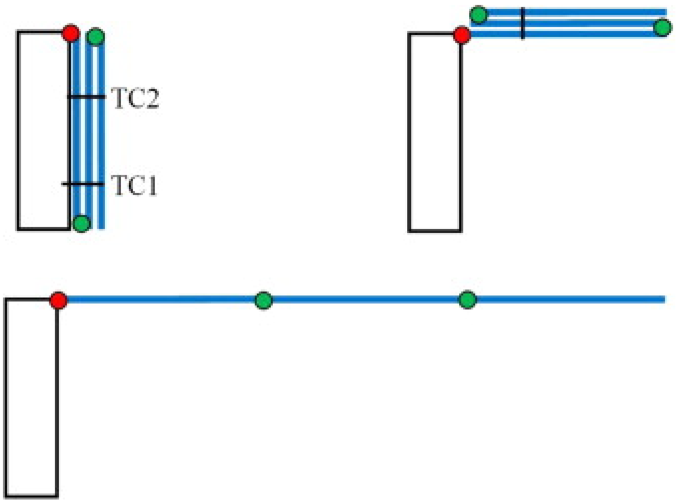
Further info on benefits of sun tracking solar panels:

https://doi.org/10.1016/j.actaastro.2013.11.011

- When looking at average total power over 1 year, a maximum of 134% improvement is seen in steerable solar panels for noon/midnight orbits
- In dawn/dusk orbits, the natural orientation of the satellite has the solar panels having the sun more often, so the fixed solar panels are near optimal. Using steerable panels only offers ~2% improvement
- Longitudinal solar panel deployment is suggested to be superior to lateral deployment for a number of reasons:
    - Less disturbance torque during deployment and less moment of inertia about steering axis
    - Less disturbance on satellite due to array drive mechanism and solar panel motion



- Potential design for solar array but scaled down for 1U:



- And then can track by adding 2 axis pivot points at the red mark

Week 3: 09/04 - 15/04

Goal

- Pick 3 possible mount designs and research strengths/weaknesses.

10/04

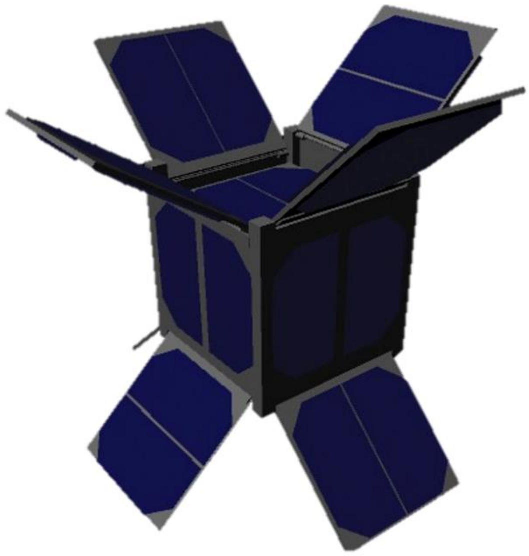
Great article: Use of Solar Panels in the Design of Small Cubesat Spacecraft

https://www.matec-conferences.org/articles/matecconf/pdf/2021/15/matecconf_icmtmte2021_03029.pdf

- Summarises how solar arrays are used in cubesats and how to achieve max efficiency + installation on cubesat
- Literature review highlights advantage of solar arrays over batteries

https://www.researchgate.net/profile/Achim-Gottscheber/publication/265102552_U_CubeSat_Design_for_increased_Power_Generation/links/54bcf6700cf253b50e2d8c2e/U-CubeSat-Design-for-increased-Power-Generation.pdf

- Doesn't allow 2-axis rotation



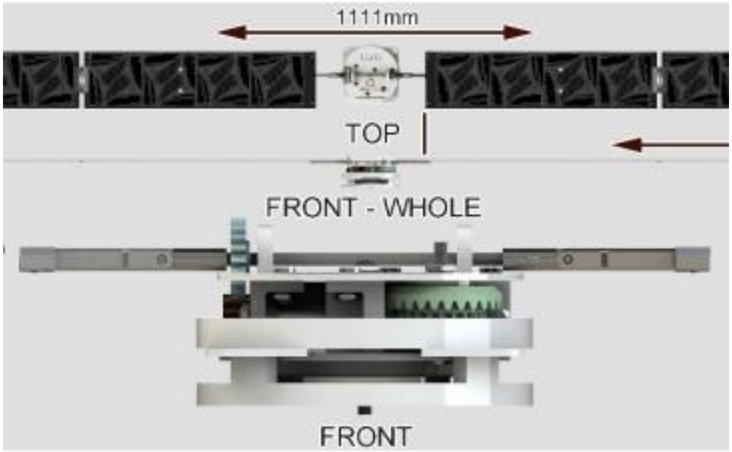
12/04 - Narrowing down designs

- Want to pick 3 designs for pro/con consideration

Design 1:

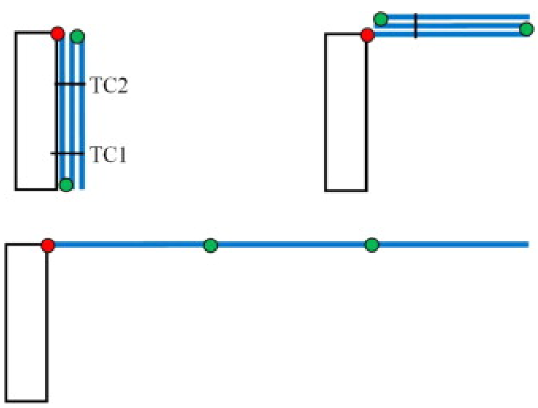
Longitudinal array with a two-axis gear box

- The design comes from a team at the University of Glascow, who designed a two-axis solar tracking system for their 3P PocketQubes (Li et al., 2017).
- Li et al. (2017) commented that CubeSats only have fixed or deployable solar panel systems on the market – but no tracking features. Just a reminder how difficult it is to design good tracking mounts.
- A 1P PocketQube is 5x5x5cm and weighs less than 200g, so the design would have to be expanded to be appropriate to fit in a 1U CubeSat.
- The design consists of a gimbal system with a two-axis gearbox.



Screenshot from (Li et al., 2017), https://eprints.gla.ac.uk/145144/1/145144.pdf

- For a 1U, panels can fold out of two opposite sides of the cube like this:



Screenshot from:
https://doi.org/10.1016/j.actaastro.2013.11.011

Pros of the design:

- Full two axis rotation achieved by gearbox and slip rings. Full azimuth and elevation range available
- Allows longitudinal deployment of foldable solar panels
    - Less disturbance torque during deployment and less moment of inertia about steering axis
    - Less disturbance on satellite due to array drive mechanism and solar panel motion

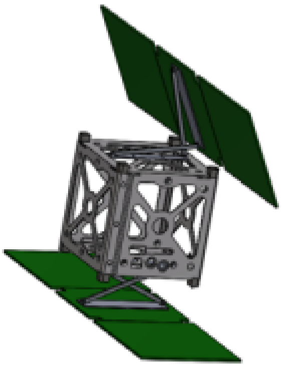
Cons:

- Gear box takes up significant space in a 1U CubeSat interior
- Springs would be required to pop the gearbox up so that the gimbal can clear the cube's rails. Added complexity may not be worth it.
- No redundancy measures. If one motor or gear fails, 2 axis tracking is lost for the whole satellite.
- Longitudinal configuration increases satellite moment of inertia -> may affect attitude control

Design 2

Double Rocker mechanism

- This design comes from McGill (2018) and is for a 1U CubeSat.
- It involves a double rocker (a four-bar linkage where both side links can rock... 🤘🤘), sitting on a revolute joint. The first axis of rotation is given by the revolute joint, built into the cube. It allows the double rocker to spin 360 degrees. The second axis of rotation is the double rocker, which can rotate over 180 degrees.



Screenshot from:
https://ecommons.udayton.edu/cgi/viewcontent.cgi?article=1172&context=uhp_theses

Pros:

- Full azimuth rotation due to sitting on rotating platform.
- Either top or bottom solar array will always be facing the sun.
- All 1U cube faces can be utilised for solar panel stowing
- Double rocker design does not take up much space when stowed.

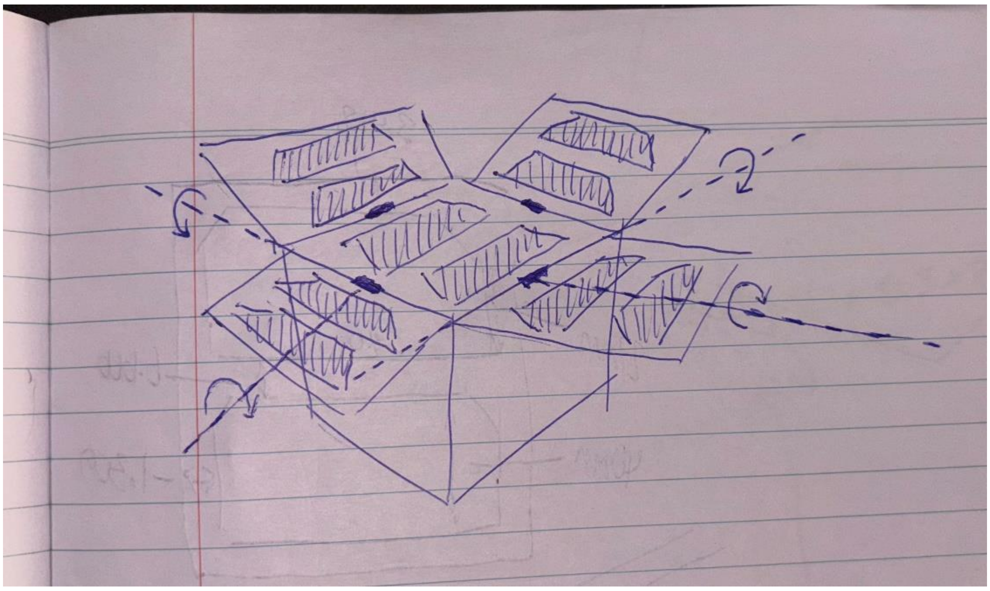
Cons:

- Only the top or bottom panels can track the sun in a single moment.
- Double rocker adds complexity that may not be necessary.

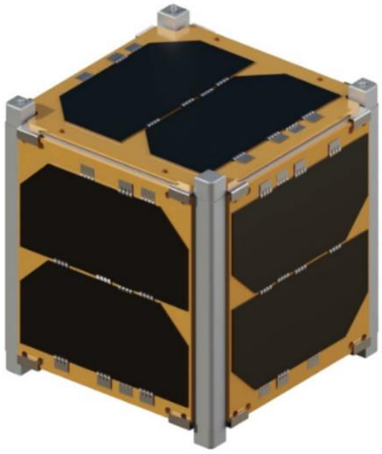
Design 3

Single solar panels with 2-axis hinges.

- This design was suggested by Aman to keep more in line with PAST's solar panel configuration – single solar panels around the XY faces and a stationary one on the Z+ face. He also suggested looking into N20 motors.
- The XY solar panels hinge at a single point where they meet the Z+ face.
- If a solar panel is mounted on the X face, rotation about the X axis will be controlled by a spinning shaft coming from inside the cube. Rotation about the Y axis will then be controlled by a spinning shaft driving a bevel gear system in the hinge. This will turn the solar panel about the Y axis.



Drawing mock-up by me



https://satsearch.co/products/dhv-technology-1u-cubesat-solar-panel

- When stowed it would look like above, and then the side panels could hinge as seen in my drawing
- With the top panel staying stationary, it means I can't have a gimbal system working out of the top face of the cube.

Pros

- Redundancy. Can have separate motors for each solar panel, meaning failure of one or more motors does not impede other solar panel tracking. Additionally, having all faces covered in solar panels guarantees some power generation if all motors were to fail.
- High power generation when sun is high (pointing to Z+ face)

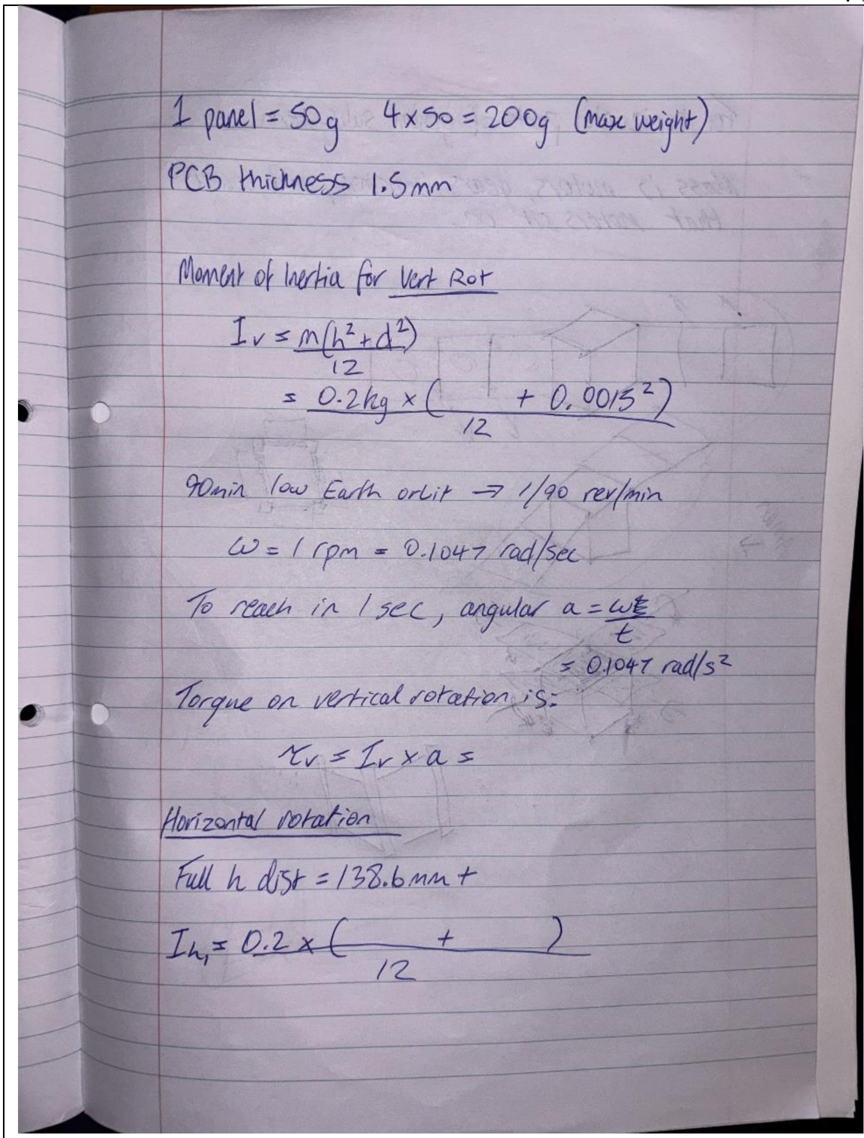
Cons

- Tracking range is limited by hinge on top face edges. If sun is high (above Z+ face), panels can hinge up and clear impedance of side of cube structure/rails. However, if sun is low, the corners of the panel can collide with cube structure/rails
- 2 motors per solar panel mean high power cost to system. Up to 8 motors to drive four panels.

13 - 15/04

- I have spent the past 3 days investigating Design 1 (2-axis gimbal) and trying to understand it and apply it to a 1u CubeSat.
- At first, I thought this design was best due to the full two axis tracking it offers and low power requirements (only 2 motors)

- To scale up the design I had to create a new gearbox, and to create a new gearbox I had to know the torque requirements.
- This involved approximating the dimensions and mass of the deployed 1U solar panels, calculate moment of inertia, and then angular acceleration required for solar tracking.
- I followed the method used by Li et al. (2017) and their suggested angular acceleration; however, the work was left incomplete because I didn't know the full dimensions of my solar panels yet.



1 panel = 50g   4×50 = 200g (max weight)

PCB thickness 1.5mm

Moment of Inertia for Vert Rot

$$I_v = \frac{m(h^2+d^2)}{12}$$

$$= \frac{0.2kg \times (\quad + 0.0015^2)}{12}$$

90min low Earth orbit → 1/90 rev/min

$\omega = 1\ rpm = 0.1047\ rad/sec$

To reach in 1 sec, angular $a = \frac{\omega_f}{t}$

$= 0.1047\ rad/s^2$

Torque on vertical rotation is:

$\tau_v = I_v \times a =$

Horizontal rotation

Full h dist = 138.6mm +

$$I_{h_1} = \frac{0.2 \times (\quad + \quad)}{12}$$

- Next, I would have calculated torque and used that to pick suitable motors and gears.

- I also found that the Dwarf Project study from PAST github will be useful to investigate solar power calculations in space, array size requirements, solar efficiency, and envelope requirements.

Week 4: 16/04 - 22/04

Goal:

- Pick best design and model in Inventor.

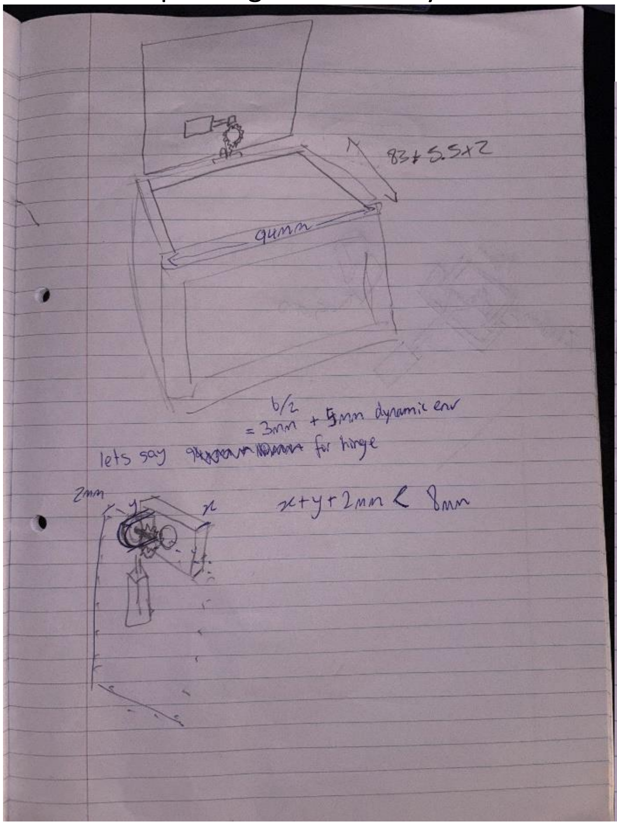
16/04

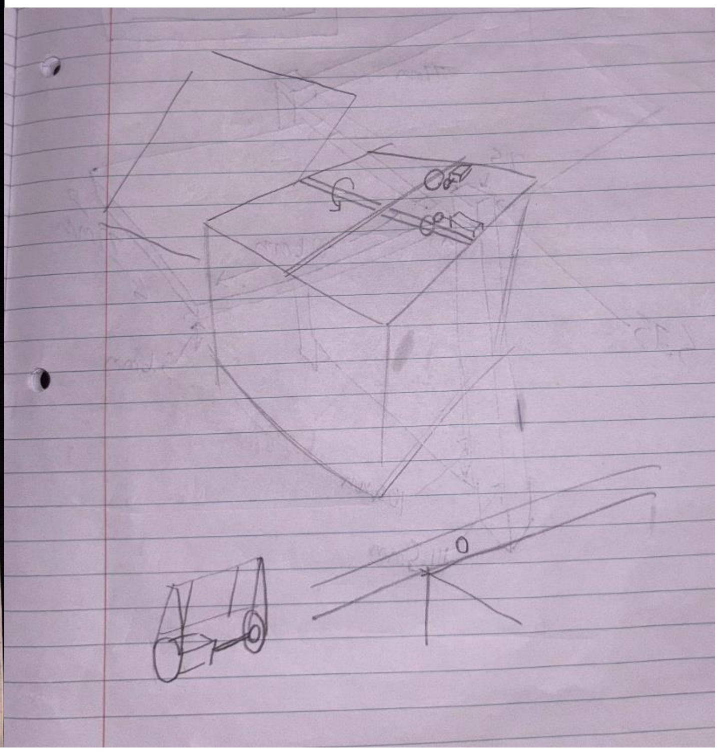
- Before today I only had 2 possible designs. Design 1 and 2 as outlined above. I was going to go with Design 1, but Aman came by my desk on the onboarding session today and suggested another idea - Design 3. He said it was more in line with what PAST was planning for their 1U.
- I've been weighing the pros and cons of each design and can see the benefits of Design 3 and how it aligns with PAST's plans.

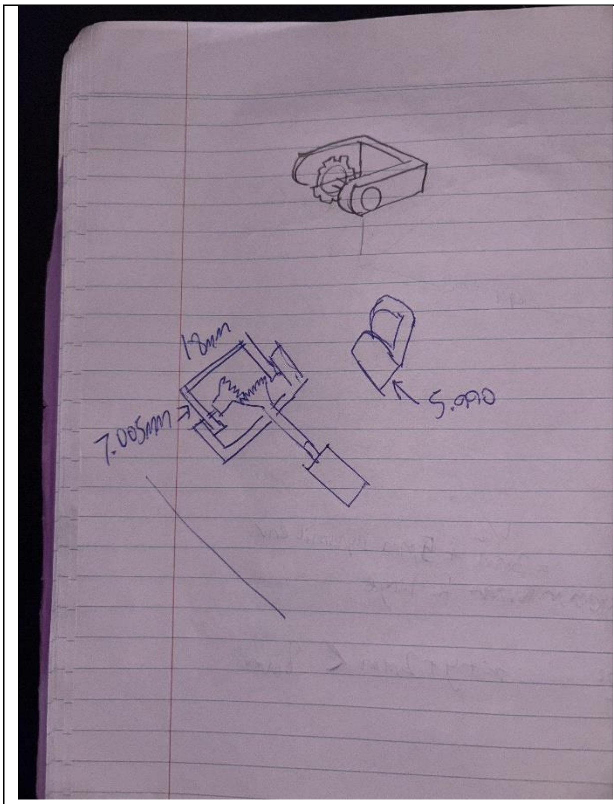
17-19/04

- Spent the last 3 days investigating this design and researching 2-axis hinges with two motors. Not a lot out there that's easy to find online.
- I believe the simplest design will involve 2 motors per solar panel, so I've started by playing around with motor placement and seeing how it would work with a 2-axis hinge.

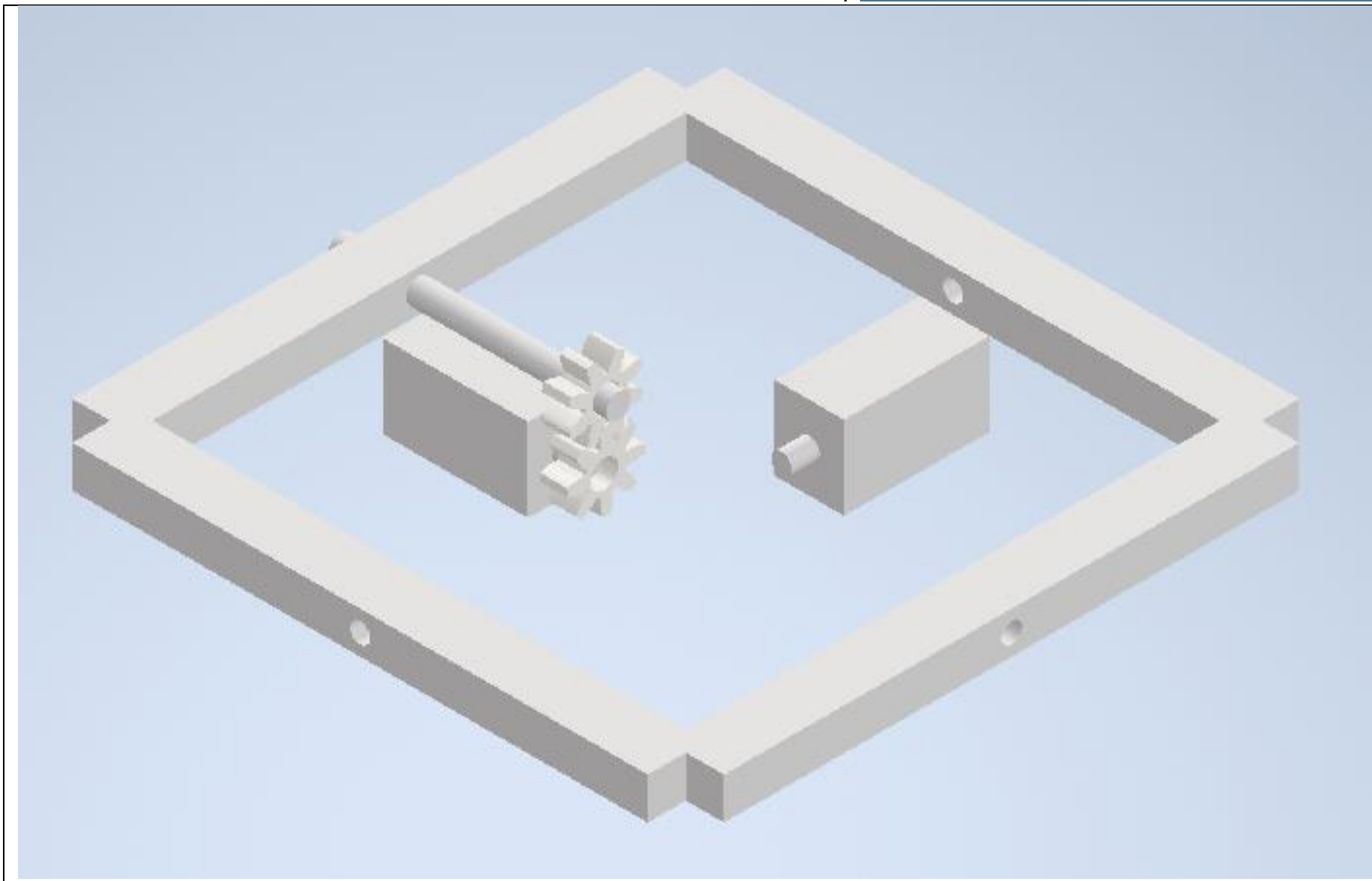
Some concept design scribbles by me:





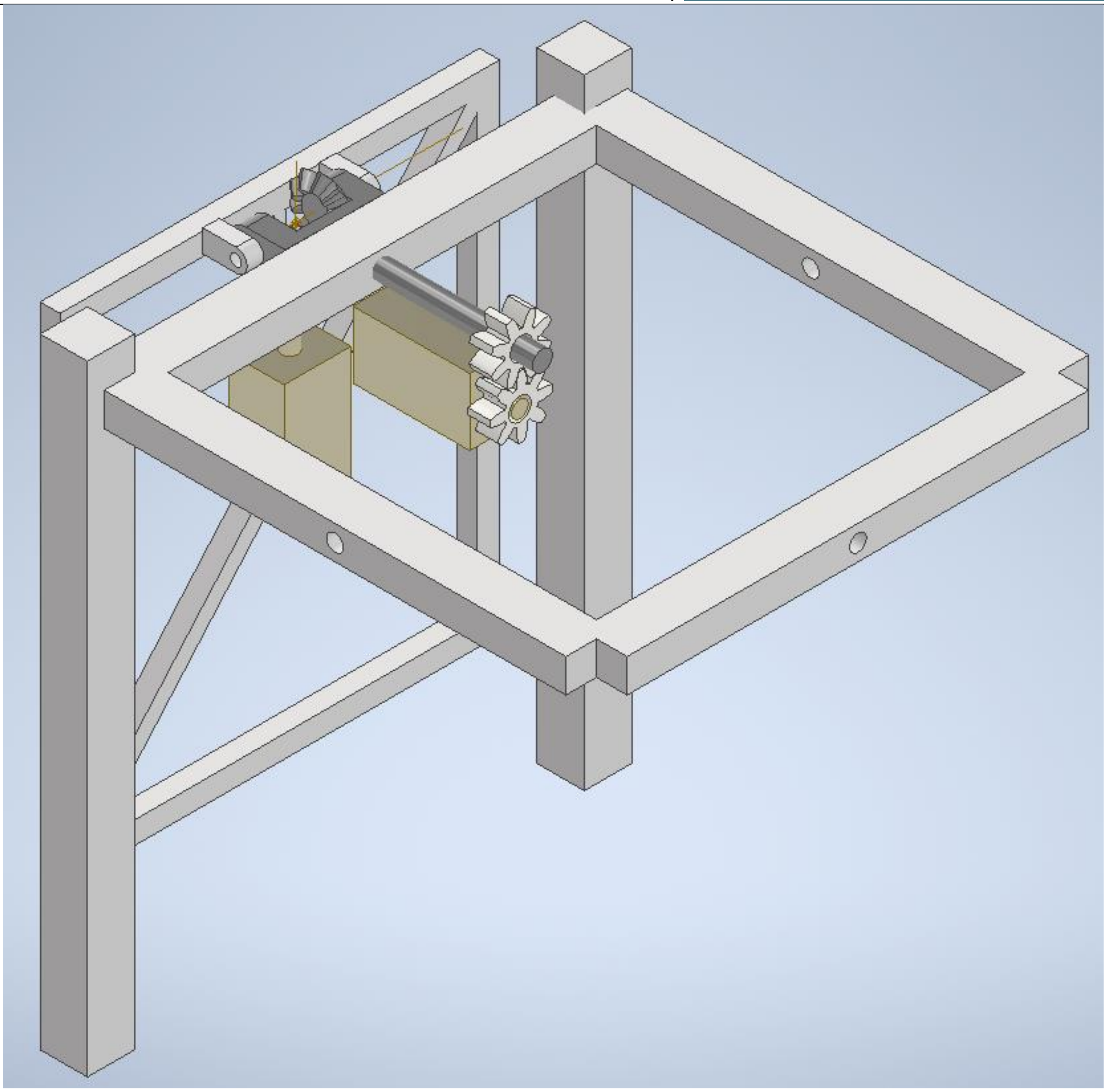


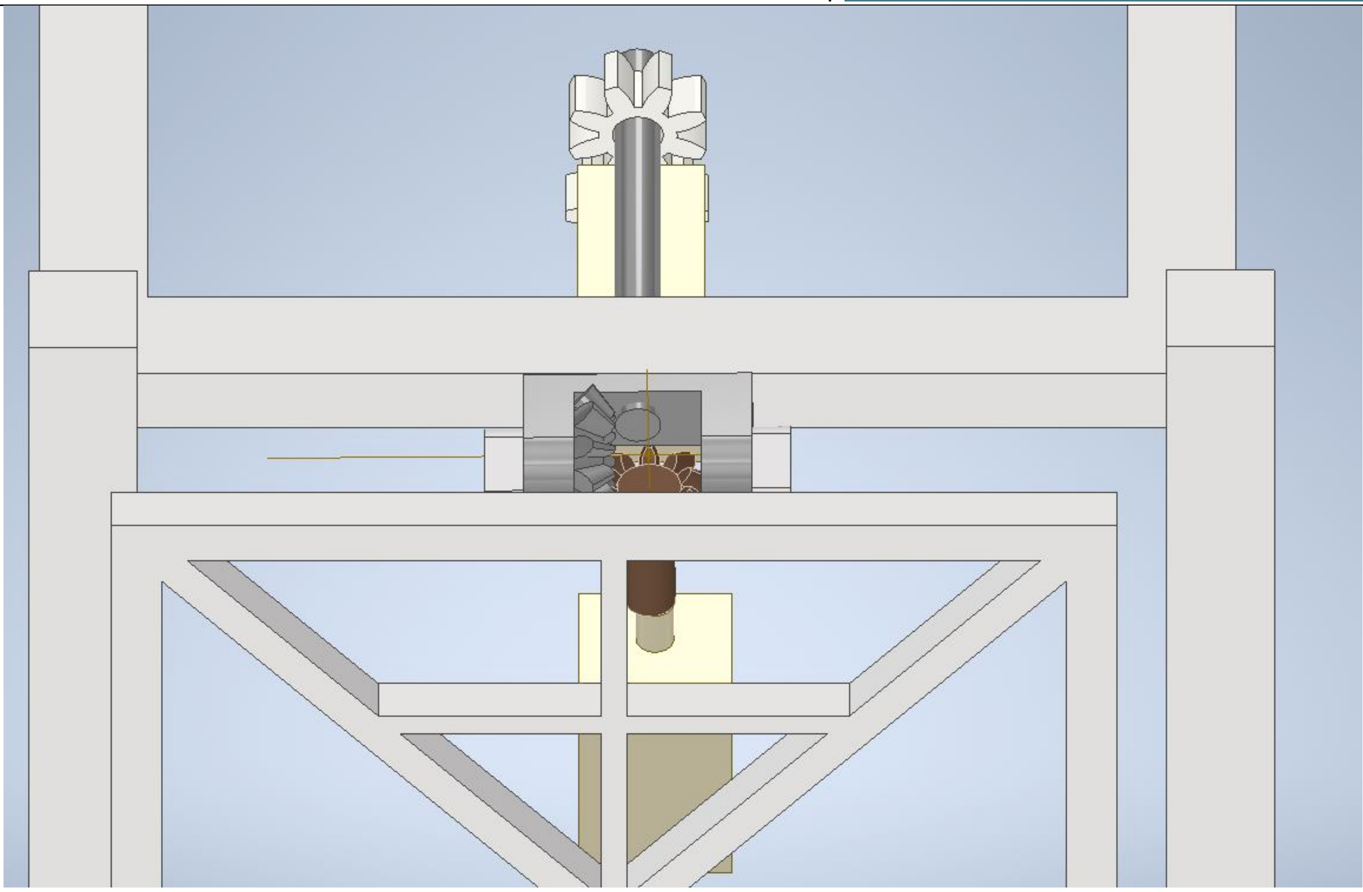
- Aman put me onto N20 motors. From them I found N10 were smaller and lighter, so I thought why not. I will have two per panel.
- For each solar panel there is one mounted to the inside of the cube structure at the top frame. This drives a shaft which will be connected to the solar panel through a bracket and one bevel gear. The shaft will turn the bracket giving one axis of rotation. If the solar panel is mounted on the X face, this rotation will be about the X axis.
- Below shows my first steps modelling this in inventor.



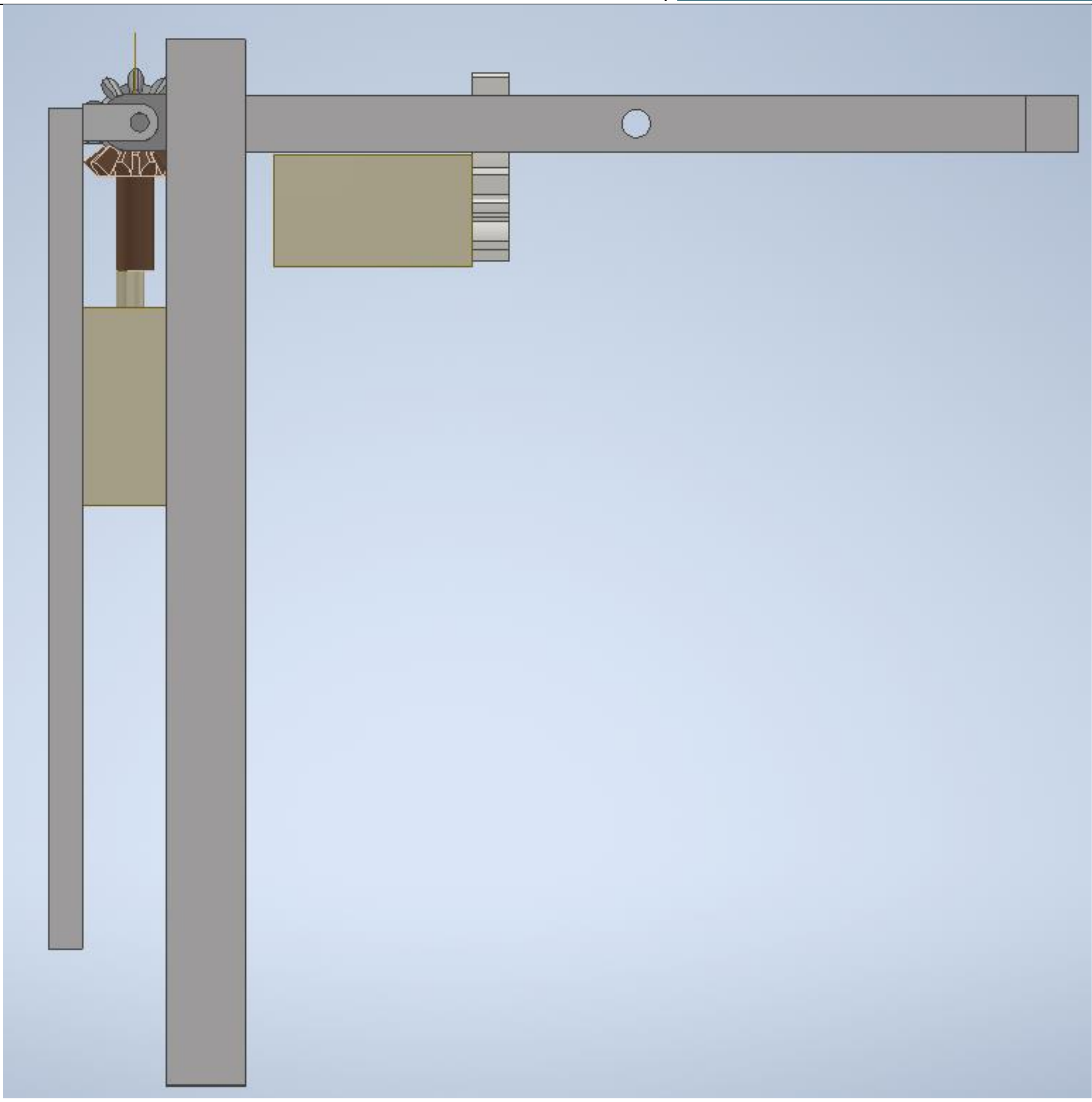
21/04

- Spent most of the day doing further work on design in Inventor
- The second motor is mounted on the inside face of the solar panel. Another shaft connects the motor to the bevel gears. This gives the second axis of rotation - about the Y axis. The motor and shaft are attached on the underside of the panel to tuck away into the cube frame as much as possible.





- Posted the design to PAST discord for feedback.
- Design was well received. Feedback was to standardise gears and keep JAXA dynamic envelope in mind.



22/04

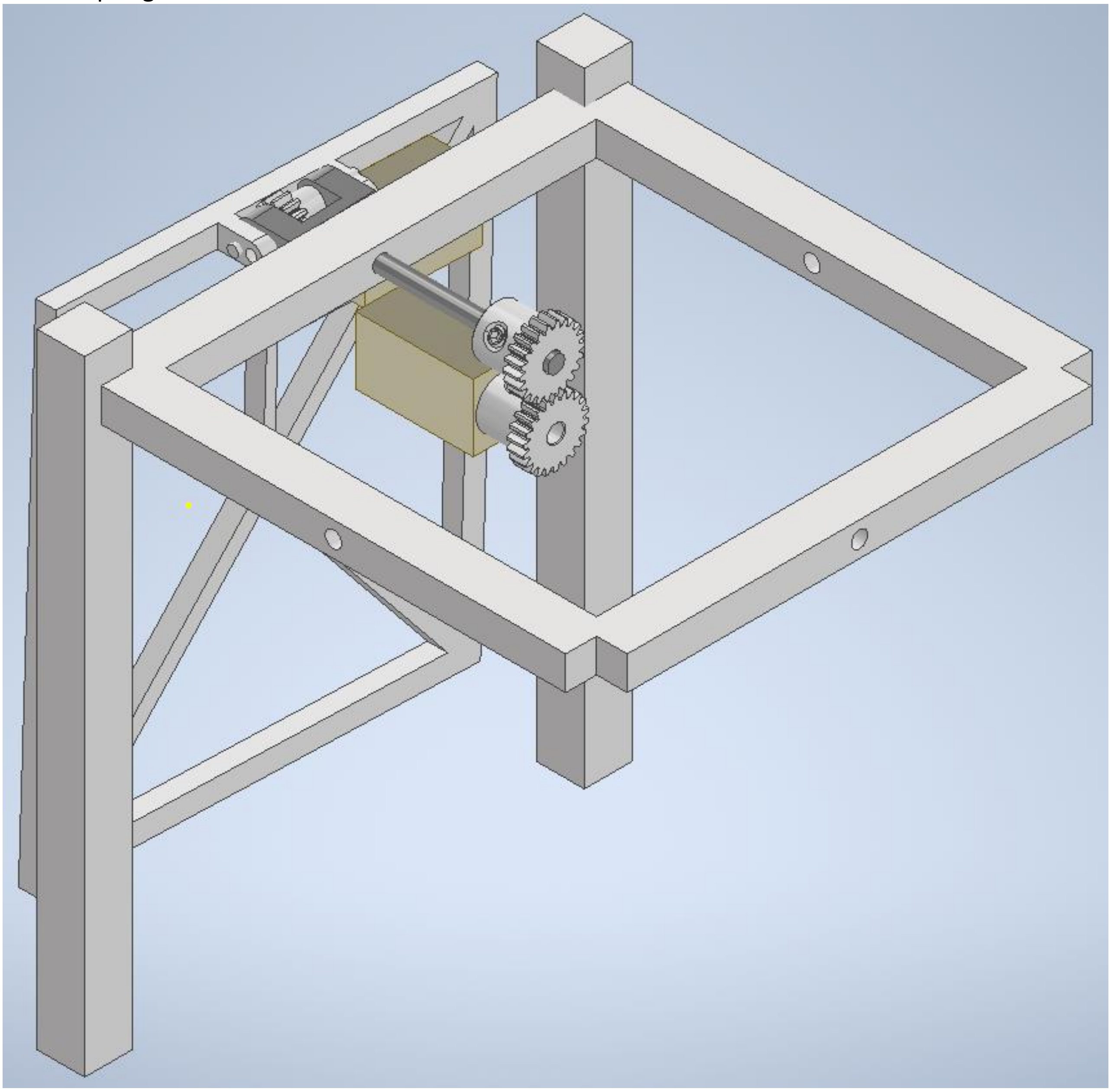
- Spent ~3 hrs starting to write up design brief -> just working on intro stuff.
- Also been polishing up the logbook.

Week 5: 23/04 - 29/04

Goal:
- Finalise model in Inventor.
- Start learning FEA's

25/04

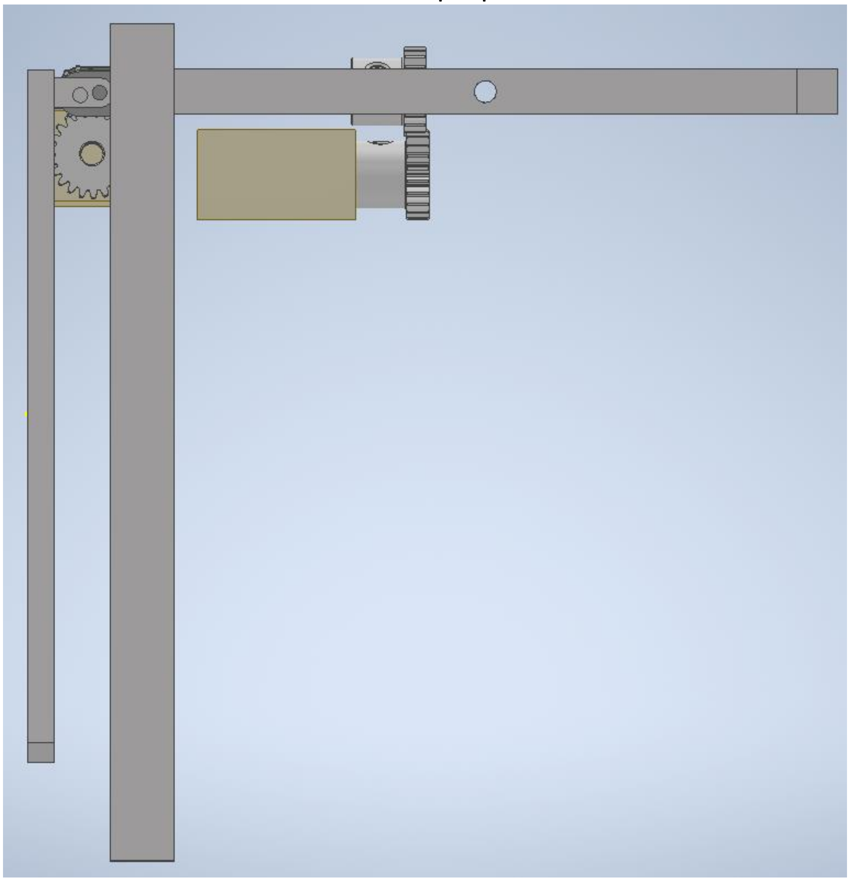
- Week has been busy 🙁. Only just got onto working on Sam's feedback. Spent half the day (~4hrs) picking standardised gears and redesigning hinge mechanism
- Sam linked me https://www.mcmaster.com/products/gears/ to look for parts
- I couldn't find small enough bevel gears on the website which led me to rethink the design using spur gears.

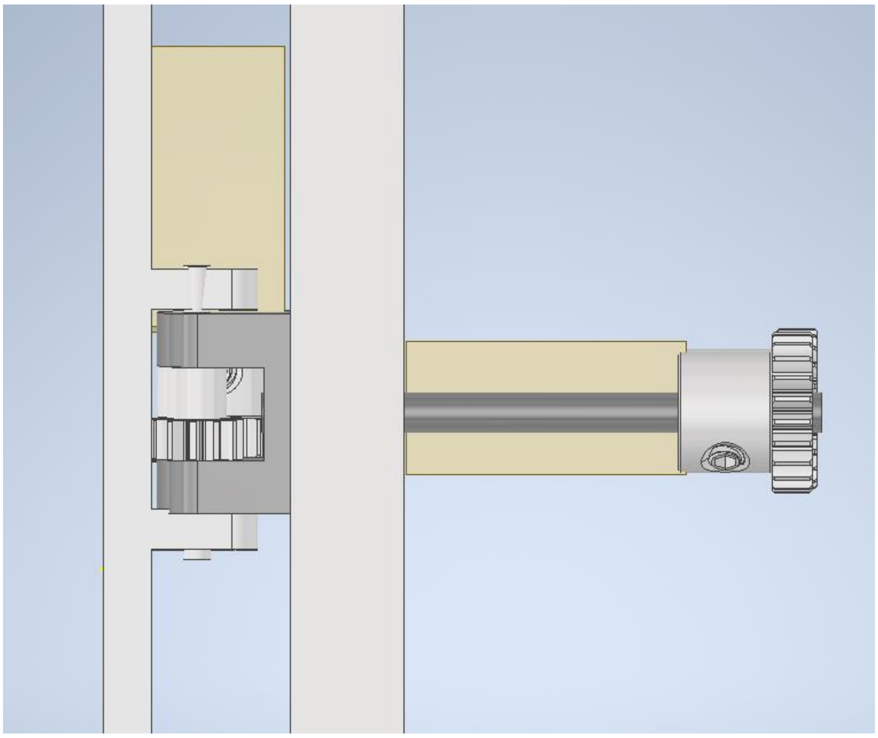


- This design is improved due to:
  - no need for a shaft on the solar panel
  - Motor is mounted closer to axis of rotation, reducing torque
  - 3 of the 4 gears now have set screws

28/04

- Optimised hinge and worked on fully constraining assembly
- Downloaded NASTRAN in preparation for FEAs



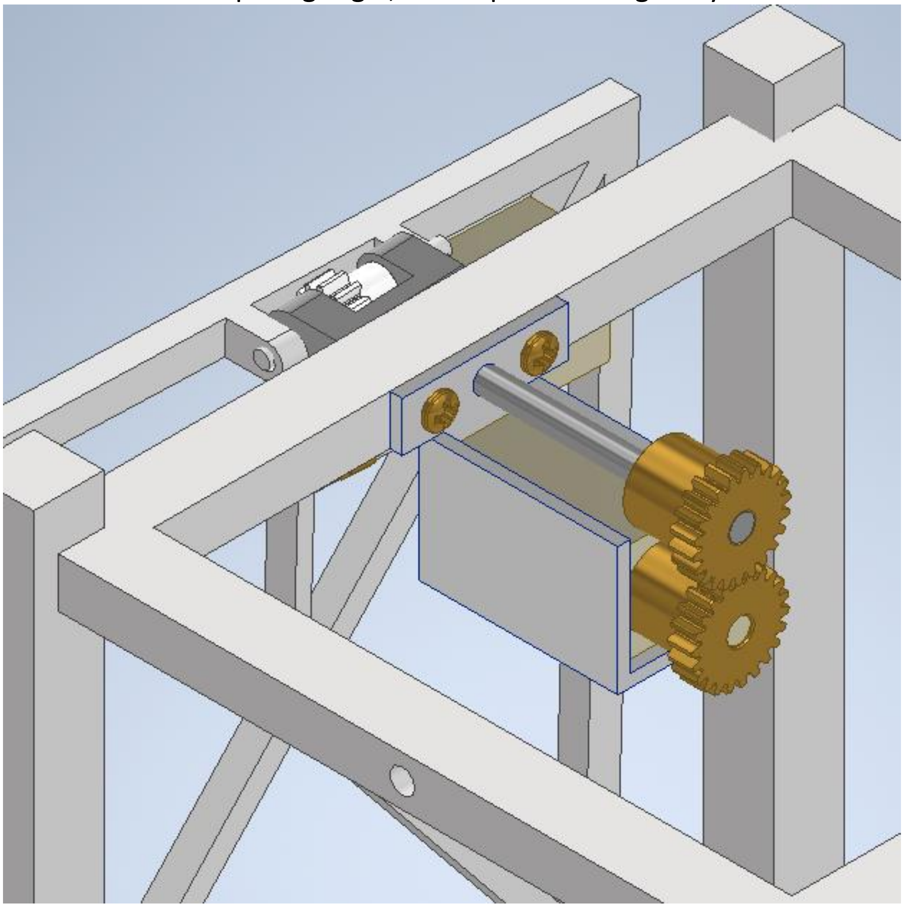


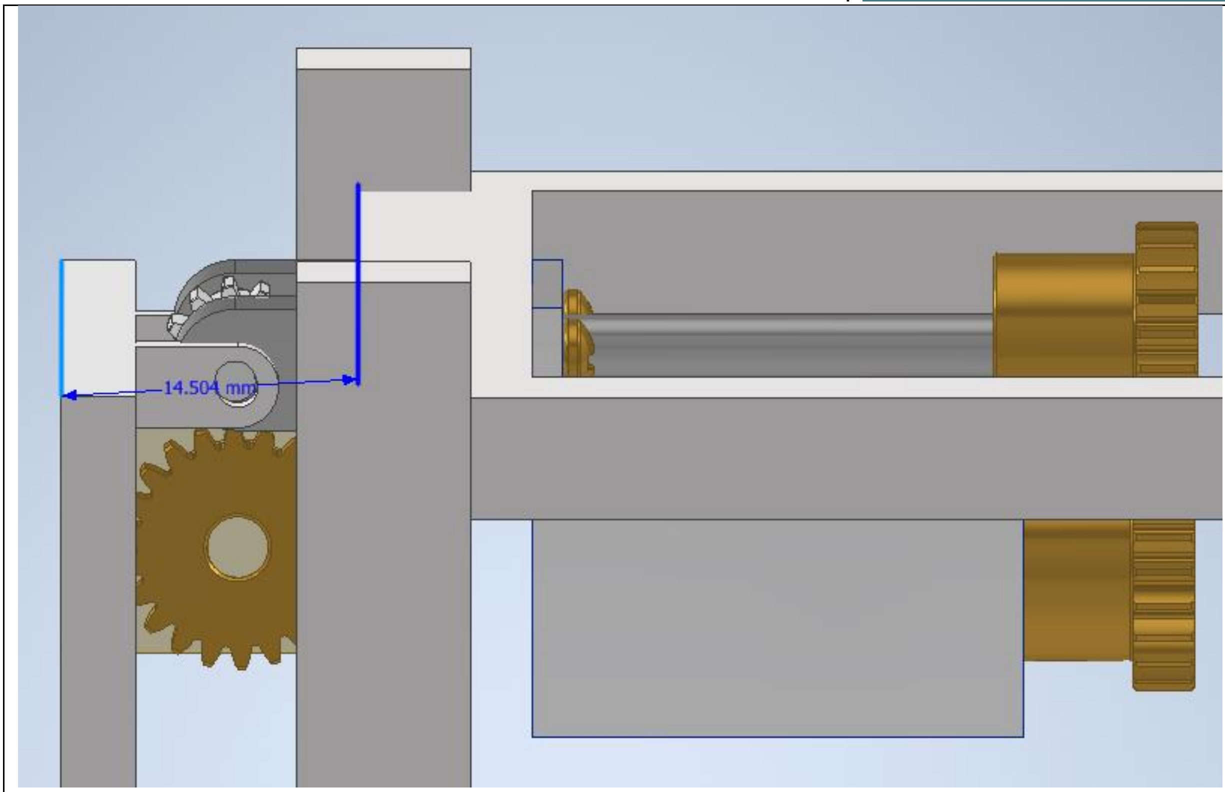
- Using spur gears made me realise the design is better having the motor mounted closer to the hinge. There is no need to a rotating shaft on the motor now, and the torque on the solar panel motor will be reduced due to mass being closer to the pivot point.

29/04

- Wk 6 starts tomorrow, and I am slightly behind schedule due to spending extra time working on improving the design based off Sam's feedback.
- I have also since learnt that we don't have to finish our projects by end of onboarding, so I should prioritise logbook and design concepts document over jumping straight into 3D printing
- what does this mean for next couple:
    - Well, my goals for wk 6 were to send the CAD model for 3D printing and work on the design concept doc.
    - Instead, I can start work on FEA's next week and work on finalising the model now.
    - Can also ask Sam questions about FEA's at tomorrow's meeting

- Added aluminium 6061 mount for internal motor. 1.5mm thickness.
- Added M2 brass screws to secure mount to frame.
- Updated gear materials based on parts from McMaster -> larger gears are brass, smaller gear in rotating bracket is acetal plastic
- Based on quick google, acetal plastic is regularly used in aerospace applications





Week 6: 30/04 - 6/05

Goals:

- Learn FEAs basics

30/04

Questions for session:

- Design concepts and overview doc finished by week 8?
    - A: no, just submit what you've done so far
- Logbook due when?
    - A: May 18th

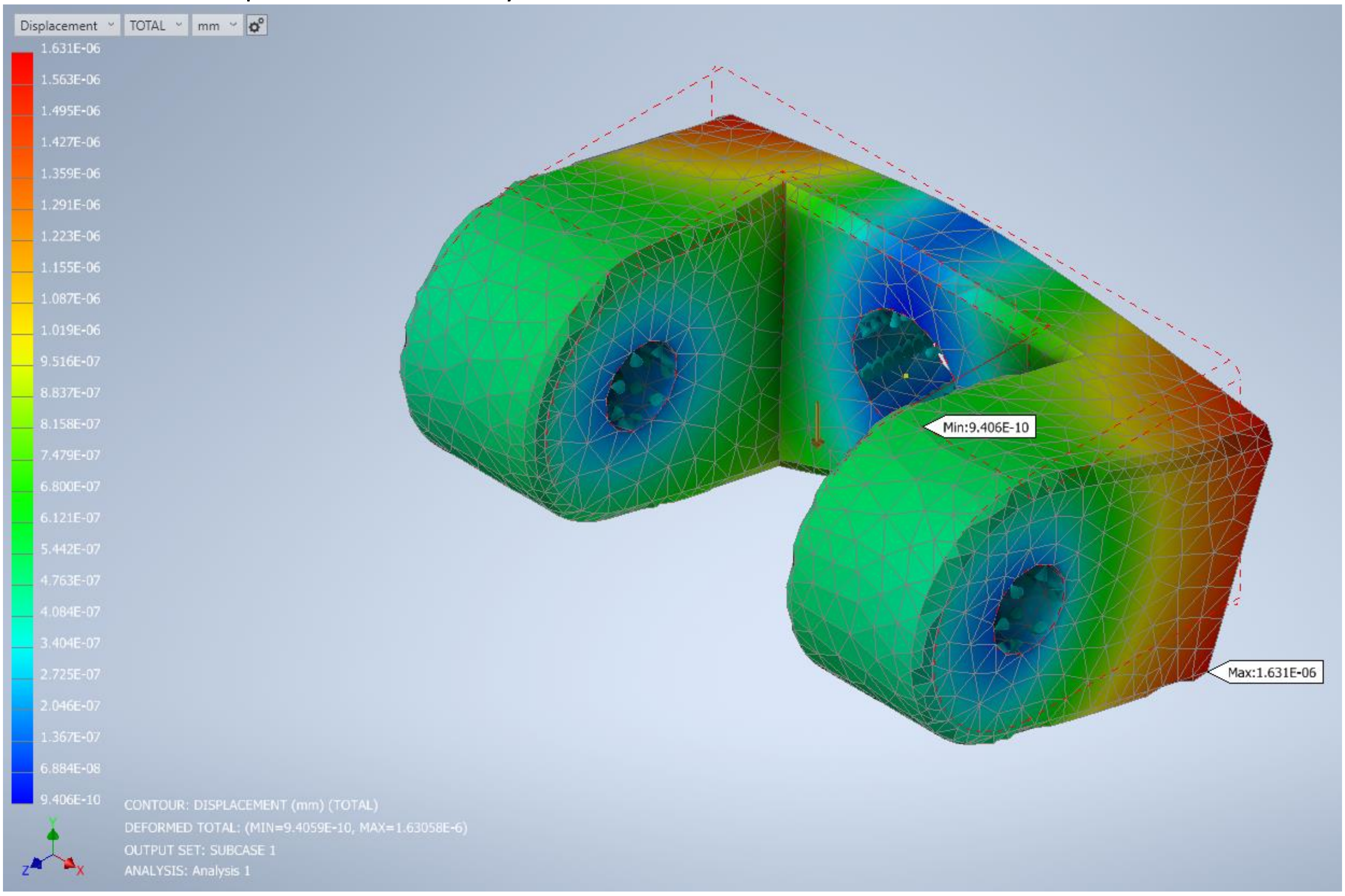
Revised timeline

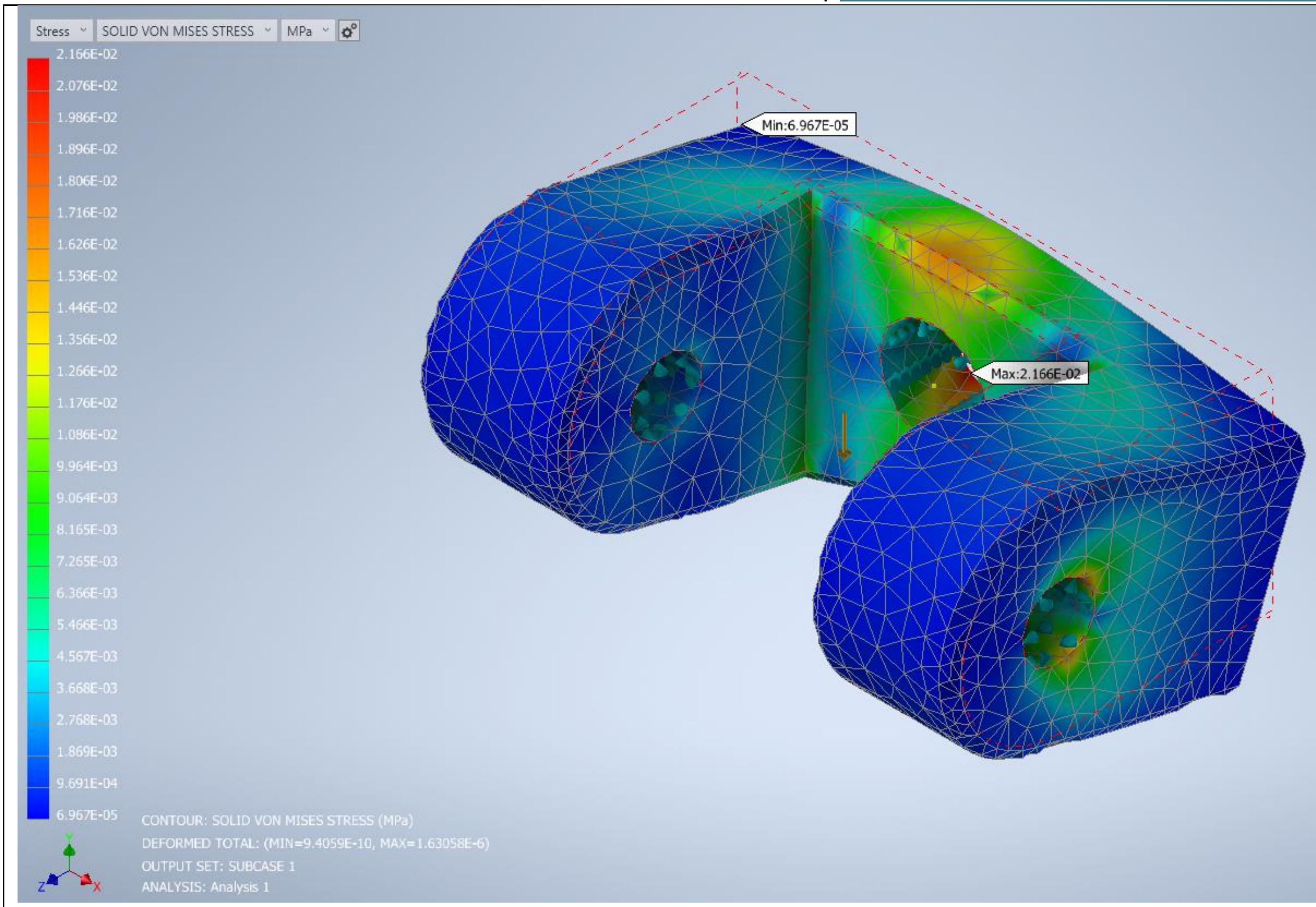
Wk 6: Work on FEAs and logbook
Wk 7: Work on FEAs and logbook
Wk 8: Write up design and concepts doc and clean up logbook

02/05

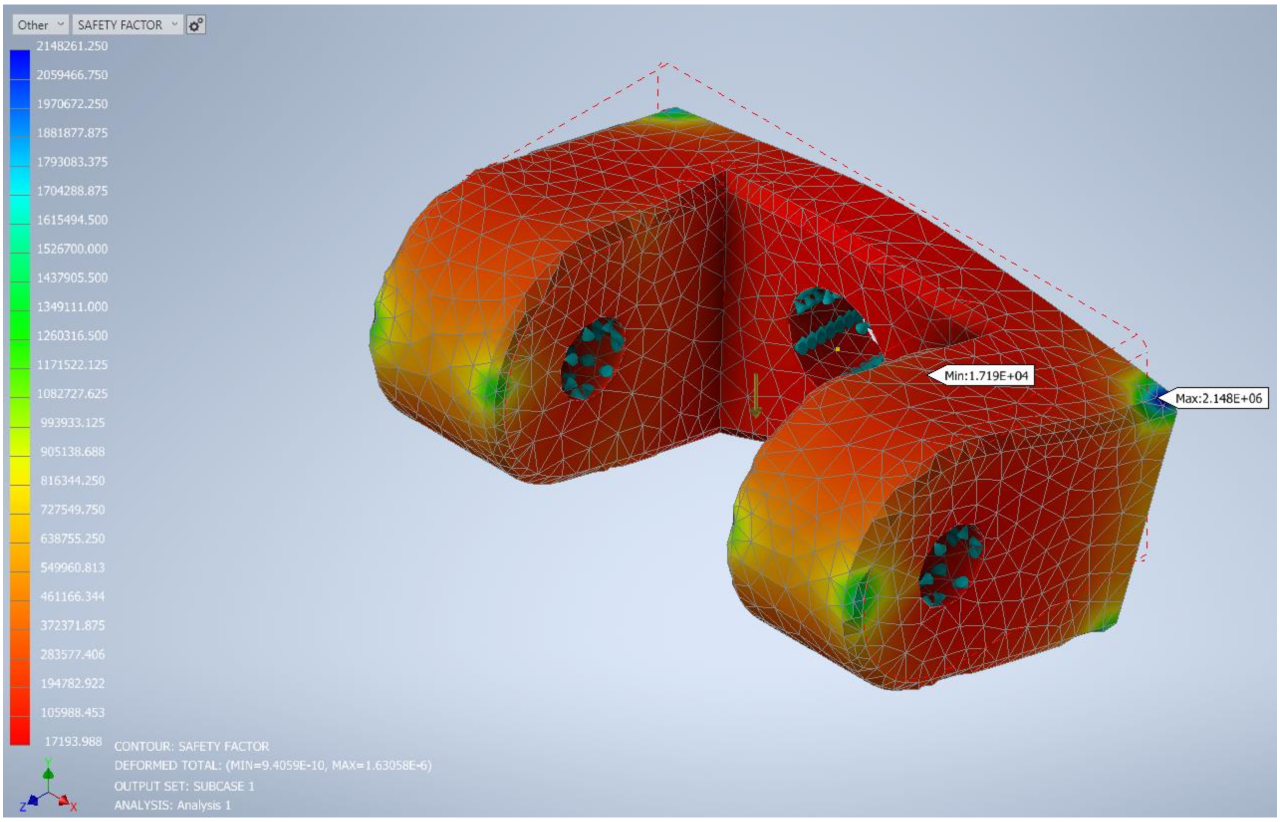
- Started learning finite elemental analysis (FEAs)
- Will do my first attempt on the simple hinge.
- Load -> Orbital Cygnus -> g = 18.1g -> * 9807 = 177506.7 mm/s^2
- Each hole was assigned 'pin' constraint

- Displacement results:
  - Max displacement extremely small -> 1.631 x 10^-6





- Solid Von Mises Stresses look very low



- Safety factor results look concerning
- Needs investigation

03/05

- Adjusted solar panel size as it wasn't exactly the same dimensions as PASTs
- Added motion constraints to gears so now I can animate the panel

Week 7: 07/05 - 13/05

Goals:

- Continue work on FEAs

07/05

- Been busy with uni assignments last several days 🙁

- Need to look at why these safety factor results look so concerning
- Need to investigate what safety factor actually is!

- Safety factor is a ratio between failure strength and expected load (Musto, 2012) https://doi.org/10.7227/IJMEE.38.4.2
- I need a safety factor of 1.5 for yield and 2.0 for ultimate load – from JAXA
- Yield strength is applied force which will permanently deform the material, and ultimate load is the maximum stress the material can endure before breaking. From: https://www.engineeringtoolbox.com/young-modulus-d_417.html

- Could potentially get more details on solar panel load before further investigating FEAs

08/05

- Asked discord for specs on solar panels

- the current panels being used are SM401K08L which are 12.3g and (W x L x H): 90 x 40 x 1.8 ± 0.3 mm https://www.digikey.com/en/products/detail/anysolar-ltd/SM401K08L/13999183
- And the PCB is 52g and 90x90mm

Week 8: 14/05 - 18/05

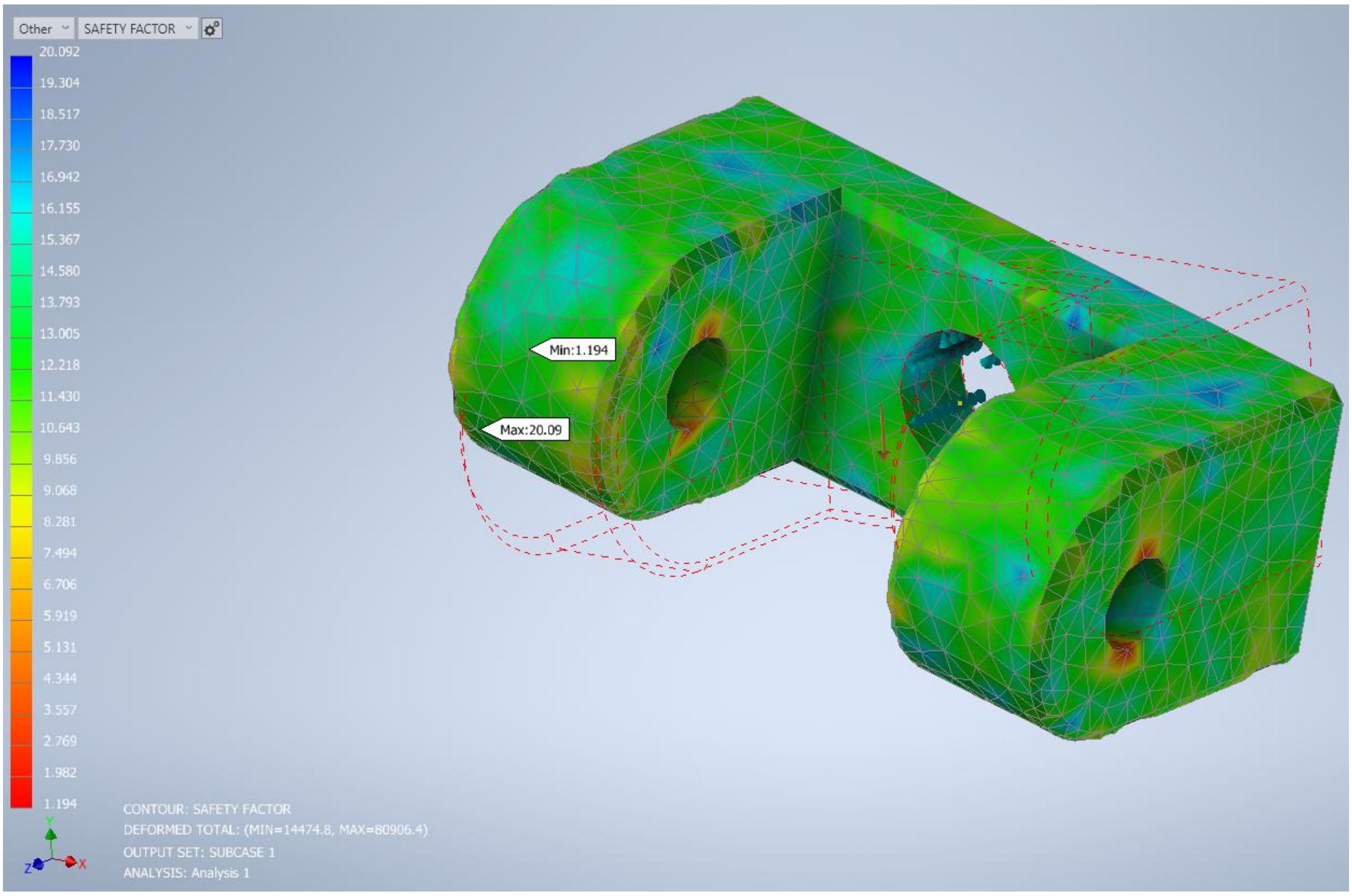
Goals

- FEAs
- Finalise as much of the reports as I can

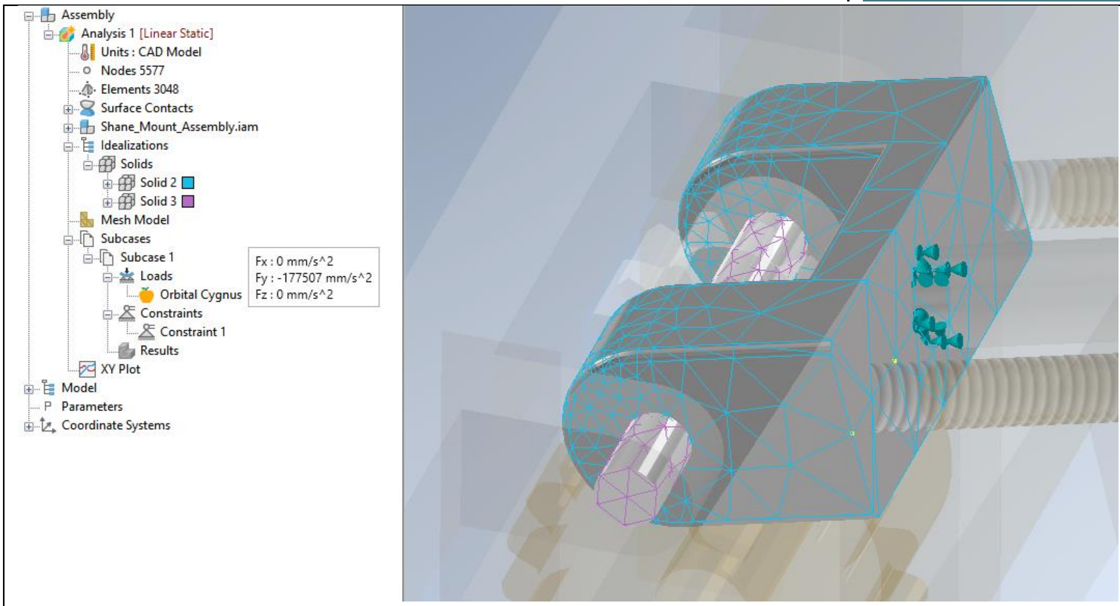
15/05

- Continuing to learn FEAs
- Going over the previous results to see what improvements can be made
- The simulation above has the hinge pretty constrained. I had it pinned to the CubeSat structure but also added pins to where it connects to the solar panel. I don't think this is accurate

- This results in some more concerning displacement results (Max of 8.091 x 10^4 mm displacement!?)
- Solid Von Mises stresses look concerning -> max 471.7 MPa is above yield strength of 275 MPa
- Safety factor looks much more reasonable than the results from before
- Max: 20.09, Min: 1.94, bit below where we want it



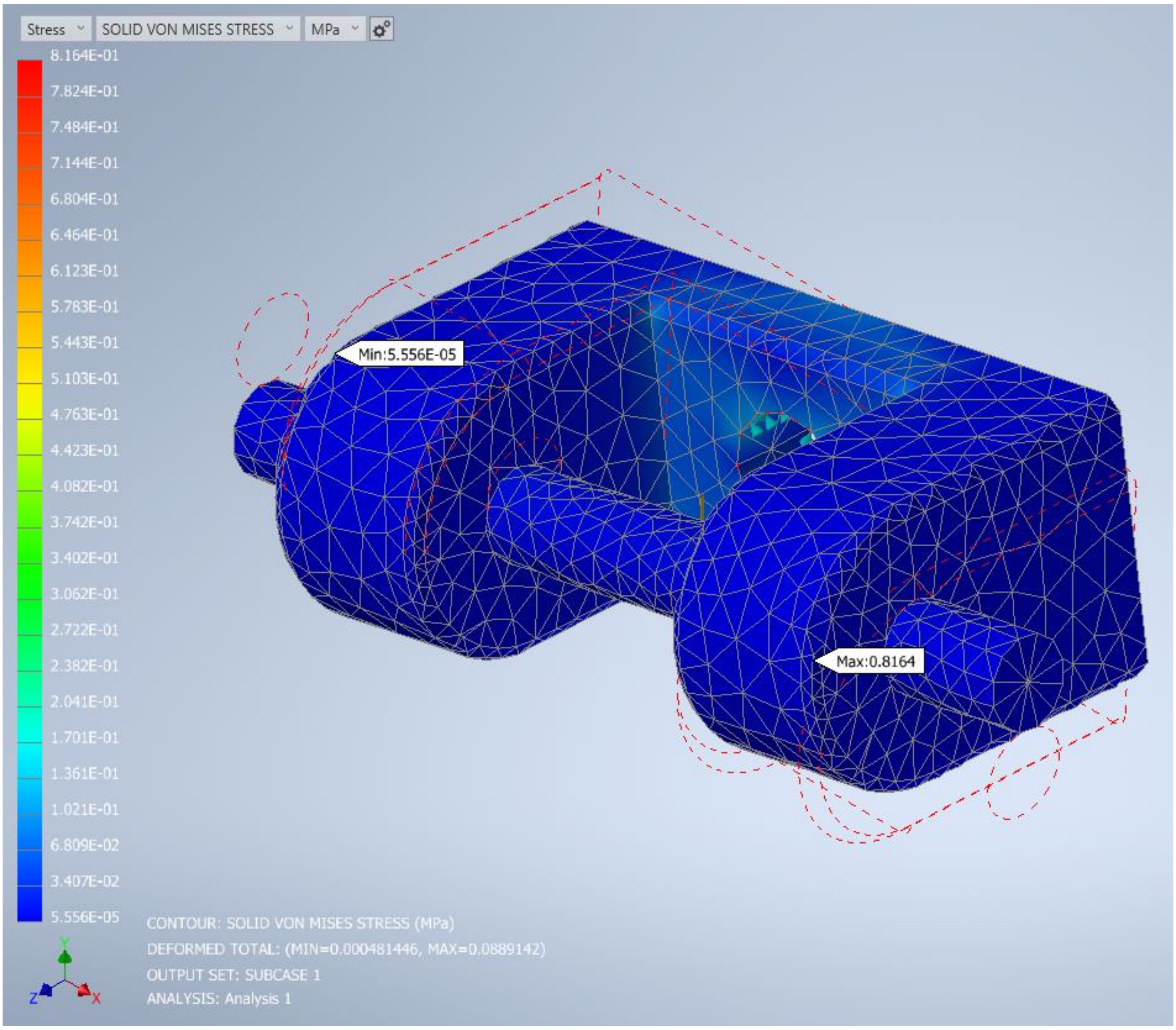
- Tried to add the hinge pin into the simulation and got a fatal error ☹



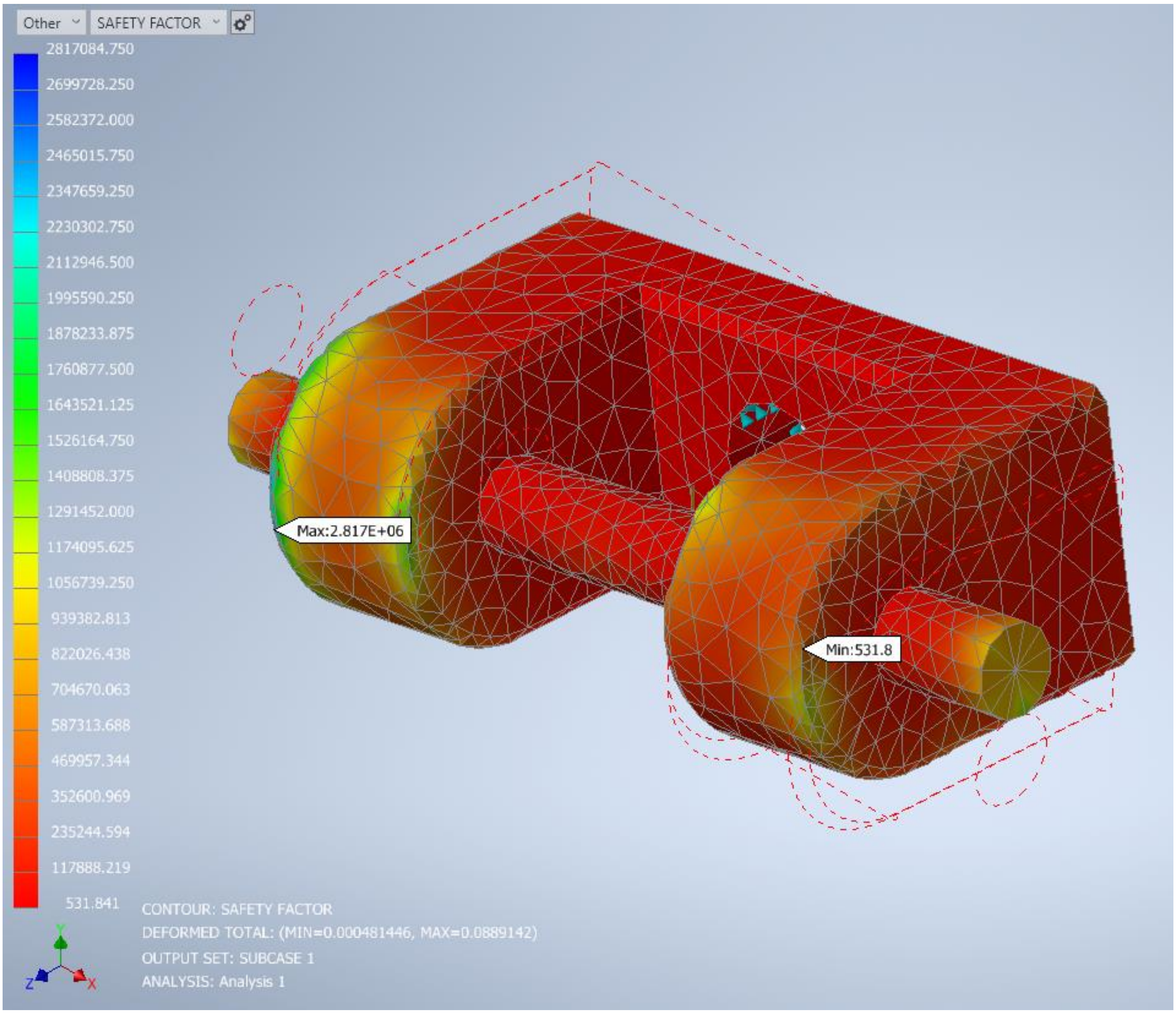
17/05 🎂

- Continuing to learn FEAs
- Regarding the Nastran errors above, I will simplify the simulation environment by putting the hinge and pin in their own subassembly and re-run simulation to see if this works
- It works!

- Max stress is 0.8164 MPa which seems too low



- Displacement max is 0.08891 mm
- Min safety factor is 531.8, which is too high



- Something must still be over-constrained

- I'm busy all day tomorrow (due tomorrow midnight) so I will have to submit tonight.
- Spent rest of day cleaning up logbook and adding more to design and concepts document.

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